

# JPL VLBI Analysis Center IVS Annual Report for 2004

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## Abstract

This report describes the activities of the JPL VLBI analysis center for the year 2004. We continue to do celestial reference frame, terrestrial reference frame, earth orientation, and spacecraft navigation work using the VLBI technique. There are several areas of our work that are undergoing active development. In 2004 we demonstrated 1 mm level troposphere calibration on an intercontinental baseline. We detected our first X/Ka (8.4/32 GHz) VLBI fringes. We began to deploy Mark 5 recorders and to interface the Mark 5 units to our software correlator. We also have actively participated in the international VLBI community through our involvement in six papers at the February IVS meeting and by collaborating on a number of projects such as densifying the S/X celestial frame and creating celestial frames at K (24 GHz) and Q-bands (43 GHz).

## 1. General Information

The Jet Propulsion Laboratory (JPL) analysis center is located in Pasadena, California. Like the rest of JPL, it is operated by the California Institute of Technology under contract to NASA. JPL has had a VLBI analysis group since about 1970. Our work is focussed on supporting spacecraft navigation. This includes several components:

1. Celestial Reference Frame (CRF) and Terrestrial Reference Frame (TRF) are efforts which provide infrastructure to support spacecraft navigation and Earth orientation measurements.
2. Time and Earth Motion Precision Observations (TEMPO) measures Earth orientation parameters based on single baseline semi-monthly measurements. These VLBI measurements are then combined with daily GPS measurements as well as other sources of Earth orientation information. The combined product is used to provide Earth orientation for spacecraft navigation use.
3. Delta differenced one-way range ( $\Delta$ DOR) is a differential VLBI technique which measures the angle between a spacecraft and an angularly nearby extragalactic radio source. This technique thus complements the radial information from spacecraft doppler and range measurements by providing plane-of-sky information for the spacecraft trajectory.

## 2. Technical Capabilities

The JPL analysis center acquires its own data and supplements it with data from other centers. The data we acquire is taken using NASA's Deep Space Network (DSN).

1. Antennas: Most of our work uses 34m antennas located near Goldstone (California, USA), Madrid (Spain), and Tidbinbilla (Australia). These include the following Deep Space Stations (DSS): the "High Efficiency" subnet comprised of DSS 15, DSS 45, and DSS 65 (see Figure 1) which has been the most often used set of antennas for VLBI. More recently, we have been using the DSN's beam waveguide (BWG) antennas: DSS 13, DSS 24, DSS 25, DSS 26, DSS 34, DSS 54, and DSS 55. Less frequent use is made of the DSN's 70m network (DSS 14, DSS 43, DSS 63). Typical X-band system temperatures are 35K on the HEF antennas. The 70m and BWGs are about 20K. Antenna efficiencies are typically well above 50% at X-band.



Figure 1. This figure shows the three high-efficiency antennas in the subnet: Goldstone is in the center; Robledo, Spain is in the lower left; and Tidbinbilla, Australia is on the lower right. These antennas were designed to have an optimum efficiency at X-band (8.4 GHz), which was to become the standard downlink frequency for solar-system exploration. An important secondary objective was to have a reasonable efficiency at Ka-band (32 GHz) thereby allowing for possible future use at the next highest band allocated for deep space communications. The subnet was completed in 1986 in time for the Voyager encounter with Uranus.

2. Data acquisition: The DSN sites have standard Mark IV VLBI data acquisition systems. We are just completing the installation of Mark 5 recorders. In addition we have a JPL-unique system called the VLBI Science Recorder (VSR) which has digital “video converters” and records directly to hard disk. The data is later transferred via network to JPL for correlation processing.
3. Correlators: The JPL BlockII VLBI correlator handles the TEMPO and CRF correlations of Mark IIIa format tapes. The  $\Delta$ DOR data from the VSR systems are correlated using the SOFTC software correlator running on UNIX or VMS workstations. The VSRs and the software correlator have also been used for connected element interferometry tests of antenna arraying concepts in preparation for arraying large numbers of smaller ( $\approx 12$  m) antennas.
4. Solution types: We run several different types of solutions. For  $\Delta$ DOR spacecraft tracking we make narrow field ( $\approx 10^\circ$ ) differential solutions. The TEMPO solutions typically have a highly constrained terrestrial (TRF) and celestial frame (CRF) as a foundation for estimating Earth orientation parameters. These reference frames are produced from global solutions which then provide the framework needed for use by TEMPO and  $\Delta$ DOR.

### 3. Staff

Our staff are listed below with a brief indication of areas of concentration within the VLBI effort at JPL. Note that not all of the staff listed work on VLBI exclusively as our group is involved in a number of projects in addition to our VLBI work.

- Jim Border:  $\Delta$ DOR
- Sid Dains: Field support of VLBI experiments at Goldstone.
- Chris Jacobs: CRF and TRF
- Peter Kroger:  $\Delta$ DOR
- Gabor Lanyi: VLBA phase referencing,  $\Delta$ DOR, WVR, CRF, and TRF.
- Steve Lowe: Software correlator, fringe fitting software
- Walid Majid:  $\Delta$ DOR
- Chuck Naudet: WVR, Mark IV support, and CRF
- Ojars Sovers: CRF and TRF. Maintains MODEST analysis code.
- Alan Steppe: TEMPO and TRF.
- L.D. Zhang: CRF and TEMPO.

### 4. Current Status and Activities

In preparation for the 2005 Mars mission, JPL is leading a collaboration with Goddard Space Flight center, the U.S. Naval Observatory, National Radio Astronomical Observatory, and the Bordeaux Observatory to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz) (*e.g.* Jacobs *et al.*, 2004).

A-WVR: The advanced Water Vapor Radiometer (A-WVR) developed for the Cassini gravitational wave experiment, continues to be used in research applications. This device can calibrate water vapor induced delays with fractional stability of roughly a few parts in  $10^{15}$  over time scales of 2,000 to 10,000 seconds. In 2004, we used the A-WVR to demonstrate a factor of three reduction in VLBI residuals on time scales of 100 to 1000 seconds.

### 5. Future Plans

We are also in the planning stage for developing a Ka-band (32 GHz) realization of the ICRF. All this work is motivated by the anticipation that spacecraft navigation will require a 32 GHz reference frame within a few years.

Mark 5 recorders: In 2004 we began integrating Mark 5 hard disk recording systems into the Deep Space Network.

### 6. Acknowledgements

The research described in this paper was in part performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

## References

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